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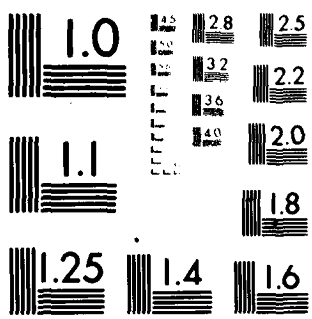

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BALLOON-SUPPORTED LORAN ANTENNA, NEW HARDWARE FOR TETHERED BALLOONS, AND PAYLOADS USED IN BANM FLIGHTS

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Analysis of corona losses on a proposed balloon-supported Loran antenna pointed the way to a workable design that was fully implemented and given an operational test. By-products of the antenna work included the production of a smart valve and useful new hardware for tethered balloons.

Payloads were prepared for and used in three successful data-gathering balloon flights for the Balloon Altitude Mosaic Measurements program.

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CONTENTS

1. INTRODUCTION 5

2. BALLOON-SUPPORTED LORAN C/D ANTENNA 6

3. NEW HARDWARE FOR TETHERED BALLOONS 8

4. PAYLOADS USED IN BAMM FLIGHTS 10

5. CONCLUSIONS 14

BALLOON-SUPPORTED LORAN ANTENNA, NEW HARDWARE FOR TETHERED BALLOONS, AND PAYLOADS USED IN BAMM FLIGHTS

1. INTRODUCTION

Effort under this contract has been principally concerned with the design and manufacture of specialized hardware to be used in balloon programs at the Air Force Geophysics Laboratory. Much of the work was concerned with mechanical problems, but the program included an extensive theoretical study of corona on an antenna, and the development of circuitry for stabilized payloads. A more complete description of the activities is contained in three scientific reports entitled "Balloon-Supported Antenna for Loran C/D Navigation System",[1] "New Hardware for Tethered Balloons",[2] and "Payloads Used in First Three Data-Gathering BAMM Flights".[3]

The report that follows is a narrative account that briefly describes the problems that were worked on, and the solutions produced. About half of the time was spent on problems related to tethered balloon programs, and the remainder was devoted to producing payloads for three data-gathering flights in the Balloon Altitude Mosaic Measurements (BAMM) program.

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1. AFGL-TR-80-0107
2. AFGL-TR-80-0108
3. AFGL-TR-80-0109

2. BALLOON-SUPPORTED LORAN C/D ANTENNA

Contract work began with a study of a balloon-supported antenna that was intended as an emergency back-up for the tower structure normally used in the mobile Loran C/D navigation system. The balloon-borne version consisted of a vertical element 500-feet long and three symmetrically spaced top loaders of 700-foot length, these being attached to three insulating tethers arranged in a symmetrical tripod. The tripod assembly, with the vertical element hanging down from the apex, was held erect by a 500-foot long tether extending up from the apex of the tripod to the balloon. Six ground radials of 300-foot length were laid on the ground directly below the vertical element. Electrical constants of this arrangement were expected to fall within the tuning range of the antenna-matching unit associated with the Loran transmitter, this being a primary requirement. But the design called for top loaders of only 3/16-inch diameter, so there was a question whether corona formation on the top loaders, when the system is operated at 78,000 volts, would burn the KEVLAR tethers to which the top loaders would be attached. Such a possibility threatened the safety of the system, and it threatened its usefulness as well because all available power could conceivably be consumed by corona.

To understand the corona situation a computer program was developed for finding the voltage gradient at all positions along the antenna elements, and this information was used to compute the losses throughout the entire system. As a comparison, a similar study was made for the tower arrangement, and based on the results of the two studies a new design was specified for the balloon-borne antenna. This differed from the original design in a number of significant ways. New top loader-tethers were procured similar to those used with the tower, a completely new and very different mechanical arrangement was developed for joining antenna elements and tethers at the apex, a rather large corona-free inverted-T was incorporated at the lower end of the vertical element to eliminate corona there and provide a convenient attachment for hold-downs, and spheres were added at the outer ends of the top loaders to reduce the gradients and the corona losses at those locations. Provision was also made in the new design for using a different, and simpler, launch procedure for erecting the tripod configuration.

As soon as the essential elements became available, the antenna was launch tested at Holloman Air Force Base to verify the workability of the revised launch plan, and to measure the electrical constants. Results were satisfactory. The revised launch procedure proved to be convenient and workable, and the measurements indicated the antenna could be tuned with the existing antenna-matching unit.

A final phase of the work with the Loran antenna involved the design and manufacture of the physically large hardware items needed to interface the transmitter facilities with the balloon-borne antenna. The problem was to provide a high current, corona free connection between the output terminal of the antenna-matching unit, which is on a breakable insulator at the top, and the feedpoint of the antenna, which is a bobbing position nominally 20 feet above the ground plane, and 10 feet above the lower end of the vertical element. An additional requirement was that the interface include a sphere gap for lightning protection. Corona-free hardware was produced, using aluminum tubing of 1.7-inch diameter, appropriately terminated by 6-inch diameter spheres. The corona-free arrangement was sufficiently lightweight to be portable. Although the structure was basically rigid, special flexible joints were incorporated to avoid straining the insulator at the top of the antenna-matching unit, and to avoid problems with a 20-foot long rigid pole that extended up from the base. Connection from the pole top to the bobbing feedpoint was by means of a 30-foot long insulated cable of 4/0 size.

After completion, the interface hardware items were crated and shipped to Anniston, Alabama where an operational test with the transmitter there was conducted by AFGL personnel. A fuller account of the work that was done on the Loran antenna, along with documentary photographs, is given in Technical Report 1 entitled, "Balloon-Supported Antenna for Loran C/D Navigation System".

3. NEW HARDWARE FOR TETHERED BALLOONS

When the test was made at Holloman to verify the launchability of the antenna, and measure its constants, there was opportunity to observe the operation. Rigging included a command package containing a command receiver, batteries, and a differential-pressure switch, all located immediately below the confluence point, with long leads and a plastic tube going from there up to the balloon valves. Reason for the command receiver was to provide for opening the valves if either the balloon should break free, or during normal deflation at take-down. Purpose of the differential-pressure switch was to momentarily open the valves if the internal pressure became excessive, and close it again when the differential pressure dropped to acceptable limits. Need for the long plastic tube was to sample the internal pressure of the balloon. The whole arrangement seemed awkward, and it added significantly to the complication of the launch. In addition a ground-based transmitter was required, and it had to be manned at all times. The real problem, however, was that the command package could not be expected to operate normally if placed in the strong electromagnetic fields surrounding the antenna. The long wires and the sensitive receiver had to be eliminated for the operational test of the antenna, which meant the safety features had to be accomplished in a different way. What was done was to design a new valve, called a smart valve, which provided the needed elements.

Requirements for a workable valve are (1) the valves should open if the internal pressure exceeds a preset limit, normally 2-inches of water, and should close after the internal pressure drops below the preset level; (2) the valves should open, and be latched open, if the balloon gets away; and (3) the valves must be openable for deflation when the balloon is taken down at the end of the operation.

The new valve arrangement used the dish, the ring, and the drive mechanism of the old EV-13 type valve, but otherwise was completely different. A differential-pressure switch of the type formerly used in the command package, but without the long pressure-sensing tube, was built into the valve assembly. Also included in the new unit was an aneroid-operated switch that would latch the valve open in case the balloon was set free. Setting of the aneroid would of course be above the normal balloon altitude, but below the altitude to which the balloon would rise if it were free to float. Batteries were also included and suitable circuitry to make the system operate correctly. Both the aneroid-operated switch and the differential-pressure switch could be removed for convenient testing and setting in the laboratory, and the battereis could be easily removed for charging. All circuitry was contained in a shielded assembly. Provision for rapid and convenient checkout of the unit, prior to flight, was also incorporated. The valve response to both types of switches could be simulated, and the circuitry was arranged to make the tests fail if either the aneroid-operated switch or the differential-pressure switch was not plugged in, or if charged batteries were not in place.

The new integral arrangement, of course, eliminated the need for a command package and the ground transmitter, and avoided the need for long wires or a long tube, but it lacked provision for actuating the valve when the balloon is brought down and deflated. This requirement was met by providing a 4-pin receptacle on the unit which made available circuit junctions that could be used to either open and close the valve as desired, or to latch it open. For most situations it would be permissible to extend a cable down from the 4-pin connector to the confluence point and actuate the valve from there at take-down, but when strong electromagnetic fields are present, and cables cannot be tolerated, the valve could be latched open by remotely breaking a tie on a spring-loaded switch mounted on the valve, this being done by jerking an insulated tag line. A special switch was designed for this purpose.

Four of the smart valves were manufactured and completely assembled, parts for four more were built, and all items were turned over to AFGL for their use. Copies of the detailed drawings from which the parts were made were also supplied to Bedford. These were used to make a complete set of drawings, including assemblies, on Air Force paper using their drawing system.

An important feature of the antenna design was the tetrahedron arrangement used at the apex of the tripod to electrically join the antenna elements at that location, and to mechanically join the tethers as well. The arrangement was lightweight and corona free, and it was intentionally made large to eliminate a twisting problem that had been encountered in earlier experiences with tri-tether rigging. This particular trouble was completely eliminated by the tetrahedron structure, a fact that was clearly demonstrated in the antenna test at Holloman. As a result it was requested that a general purpose tetrahedron of similar sort be built, and this was done. The design was similar to the one used with the antenna, and it too had an ultimate strength of 20,000 pounds, but the fancy corona-free terminations were replaced by simple eye bolts. Also included in the design was provision for the fourth tether that is used for balloon let-up in the revised launch procedure, this replacing the earlier technique that had used one of the tripod legs for let-up after the balloon reached an altitude of 500 feet.

In observing the antenna tests at Holloman it was evident that the rigging was excessively cumbersome, and could be simplified. As a result some new hardware items were designed which could eliminate 10 of the shackles, and a triplate, that had been used at the confluence point to join the 16 flying lines at that location. The new hardware required no wrench-tightening, and no safety ties, and it was easy and fast to incorporate into the rigging. Its rated strength was equal to the combined ultimate strength of the flying lines on the balloon, so should be a useful item in the hardware inventory at Holloman.

4. PAYLOADS USED IN BAMM FLIGHTS

Intensive work for BAMM began in May 1978 and continued through to the end of the contract, including the three months extension that was necessary because the third flight, which had to be made at the time of the fall turn-around in October, would have taken place after the contract ended. Work with BAMM was an enormously demanding, and a particularly successful, part of the contract effort. It involved the production and flight use of three significantly different stabilized payload arrangements.

The first BAMM flight carried a TV camera for real time monitoring of the ground scenes being studied, and a radiometer for gathering infrared data. Of course it also carried essential peripheral items, including command facilities, telemetry equipment, balloon control circuitry, a commandable ballast arrangement, and electronics for the TV and the radiometer. In addition the platform was stabilized in azimuth, using a gyrocompass as a reference, with provision for commanding changes in the heading angle at either of two rates. Also, the elevation axis was controllable by command, again at either of two rates, but without servo stabilization about the elevation axis.

Preparation for the first BAMM flight required that a workable gondola be produced in a short time, starting with a skeleton framework that had been put together during an earlier contract. As originally built the gondola framework included a gimbal that could move through 90° about an elevation axis, and a small platform that could move $\pm$ 10° about a cross-elevation axis. In the earlier system the entire gondola was rotated in azimuth by means of a powered rotator placed in the suspension system. A rotator of this type was available for BAMM use. The gondola structure also included ballast hoppers, but without ballast valves, and two thermally-insulated packages where instrumentation could be located. It was an assembly of spare parts that had been produced for refurbishing a 24-inch balloon-borne telescope system.

To make the system useful it was necessary to enlarge the rack to accommodate a larger thermally-insulated package on one side, replacing the existing one, to eliminate the cross-elevation feature, to design and make a drive mechanism for controlling the elevation axis, this to be commandable at either of two rates, to design and make the instrumentation needed to stabilize the gondola in azimuth, and to provide commandable control of the azimuth heading at either of two speeds. Of course the integration of all components, including the planning and doing of the necessary wiring, also represented a sizable task. Although the time available for designing and building the essential components was short, the problems were successfully solved sufficiently before the fall turn-around arrived to allow preflight testing and checkout of the system. Launch of the first payload arrangement was accomplished with complete success on 28 September 1978. It represented the first data-gathering experiment in the BAMM program. Recovery in this instance was unique in that the payload landed astride the center line on a highway, and stood upright with the chute fluttering gently to the ground at the side of the road. Absolutely nothing was damaged, including the sensitive radiometer.

Plans for the second BAMM flight were much more ambitious, and the grueling schedule was more demanding than had been the case for the first flight. Reason was that a large and heavy interferometer, with its associated electronics, had to be incorporated into the limited space available within the gondola framework. In doing so it was also necessary to provide essential access for alignment and adjustments, and for filling the radiometer and interferometer with liquid nitrogen. Meeting these access needs considerably complicated the problem of fitting the equipment into the confined space, as did meeting the field-of-view requirements for the sensing instruments. A month of study was spent in finding a way to solve the problems. The resulting plan necessitated discarding the entire central assembly that had been used for Flight 1, including the elevation drive mechanism, and replacing it with a new and more complicated arrangement. An important feature of the new plan was that the cross-elevation axis could be restored, which would make it possible to keep the instruments pointed at a particular ground target by continuously changing the elevation and cross-elevation angles to compensate for balloon movement. Implementing this, of course, would require servo drives in the mechanisms that control the two axes, and it would require reasonably complicated computer circuitry to generate the control signals needed for these drives. Inputs to the computer circuitry would be azimuth heading, elevation angle, cross-elevation angle, wind velocity, and wind direction.

Schedule for completing the work was fixed, and short. To be useful the new payload had to be ready for flight use at Holloman, including thorough preflight testing, before the spring turn-around in May. The new structure was designed and built, new drives for the elevation and cross-elevation axis were designed and built, provision was made for more batteries and additional instrumentation within the thermally-insulated packages, and much of the electronic circuitry was worked out before the system was moved to Bedford where system wiring, interface testing, and preliminary checkout was accomplished. Subsequently the near-complete system was shipped to Holloman for final testing and preflight checkout. The new payload was successfully launched on 29 May 1979. All elements of the gondola worked as planned, and for the first time in the BAMM program, interferometric data as well as radiometric data were collected on the chosen targets. Only one feature of the original ambitious plan was not complete, namely the compensation circuitry; it was operable for the cross-elevation axis, but not for the elevation axis. Recovery was by ground impact, as it had been for Flight 1, although provision had been made to carry the MARS chute if midair recovery could be scheduled. Unlike Flight 1, which landed so gently, the payload fell on a hillisde in a difficult area, with some damage to the rack structure. However, none of the sensitive instruments and none of the electronic equipment was harmed. The payload had lived to fly again, but whatever its future, important data were already in hand from an interferometer and a radiometer, both looking at the same target, with a TV record of the same scene.

Flight 3 was scheduled at a coastal location, Keesler Air Force Base, at the time of the fall turn-around. There was adequate time to refurbish the gondola framework that had been damaged in Flight 2, and for accomplishing the necessary preflight preparations, but not for improving the system. Nevertheless, three significant improvements were crowded into the preparation plans. Both drive mechanisms were modified, a gimbal lock was designed and manufactured, and the remaining circuitry needed to compensate for balloon motion was completed. Reason for changing the gear drives was that the original design had employed large worm gears at the output to avoid the necessity for locking the central assembly during recovery. But this considerably reduced the available torque, which meant careful balancing was required. Torque was restored by replacing the worm arrangement with spur gears, but the change made it necessary to design and make a commandable locking device to securely hold the central assembly at the time of parachute opening, and during recovery.

Preparations for BAMM Flight 3 were fully completed, including all essential interface and preflight testing, several days before the fall wind reversal. For this flight the optional rigging for air snatch was used. A near perfect launch was made on 8 October 1979. During ascent and throughout the flight the payload performed precisely as planned, as did the balloon, which followed a path that made all of the desired targets available for study. Termination and descent were normal, and a midair recovery by helicopter was executed precisely as planned. As a consequence the payload was returned to the launch area with no damage to any of the vital instruments or components. Flight 3, like its predecessor, produced both radiometric and interferometric data, but in this case from different targets. It was also the first instance in the BAMM program where a live payload was recovered in the air.

5. CONCLUSIONS

All projects undertaken under the contract were successfully completed. This included a theoretical analysis of corona on an antenna structure, design and manufacture of components for a balloon-borne antenna arrangement, design and manufacture of hardware for making an operational test of the balloon-borne antenna, design and manufacture of a smart valve for use with tethered balloons, design and manufacture of two items of special hardware for tethered balloon use, design and manufacture of three different payload arrangements for BAMM, design and manufacture of the electronics needed for azimuth stabilization of of each payload, and the design and manufacture of facilities needed to hold the line-of-sight on a particular ground target when the balloon is moving.